

# Analysis of Low-Speed Stall Aerodynamics of a Swept Wing with Laminar-Flow Glove

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# Outline of the Presentation

- Objectives of the present analysis effort.
- Description of the NASA Dryden GIII SCRAT testbed aircraft and the SARGE DRE laminar wing glove research proposal.
- Validation of the Star-CCM+ CFD code for low-speed wing stall analysis.
- Low-speed stall aerodynamics of the SARGE gloved wing and comparisons with the clean wing.
- Conclusions and recommendations.

# Objectives

- Validate the Star-CCM+ CFD code for low-speed wing stall prediction.
- Quantify the effects of grid sizes and turbulence modeling parameters on Star-CCM+ wing stall analysis.
- Determine if the addition of the laminar-flow wing glove to the left wing changes the low-speed wing stall characteristics from the unmodified/clean wing.
- Determine the flow physics behind low-speed gloved wing stalls.

# NASA Dryden GIII SCRAT Testbed Aircraft



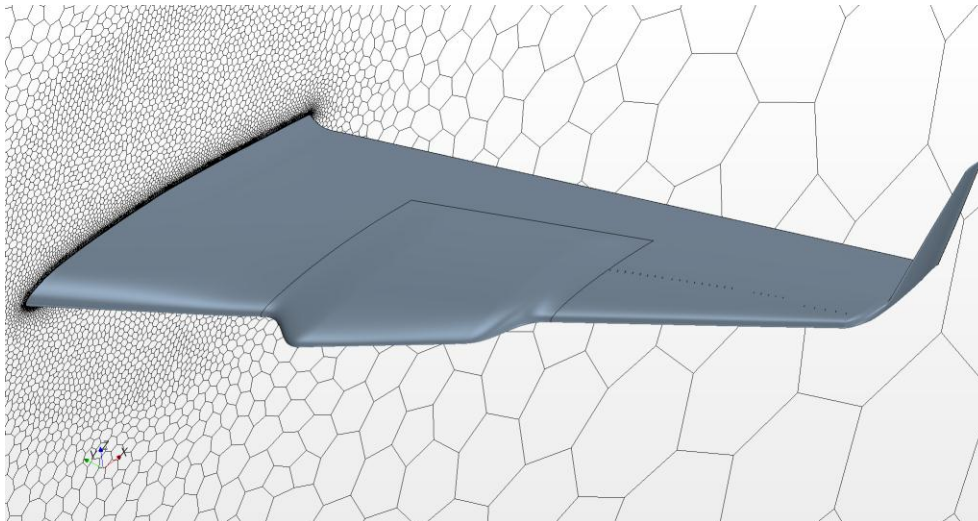
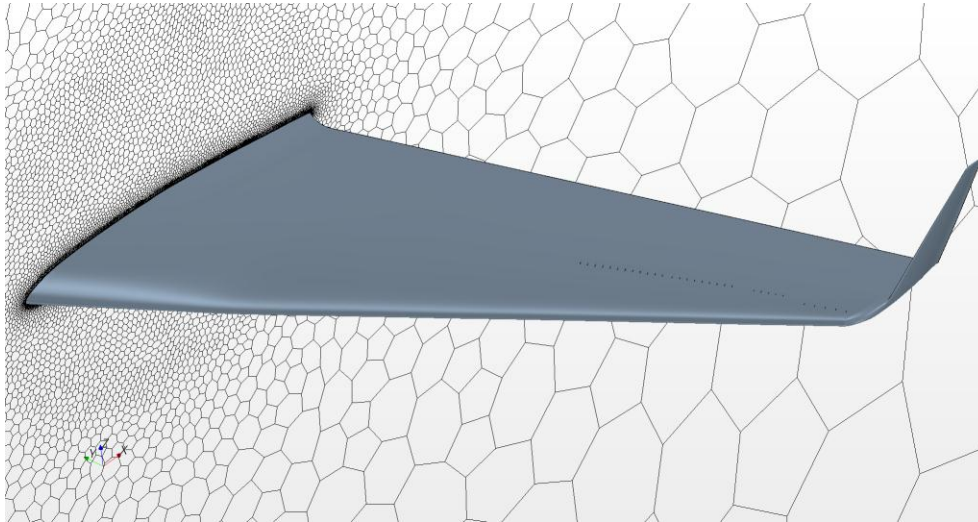
- NASA aircraft tail number 804.
- Subsonic Research Aircraft Testbed (SCRAT).
- A modified Gulfstream III (GIII) aircraft used for conducting aeronautics research both internally within NASA as well as with external partners.
- Recent projects include the NASA ERA/TAMU SARGE laminar flow glove and the AFRL ACTE compliant flap.

# The SARGE DRE Laminar-Flow Wing Glove Flight Research Proposal



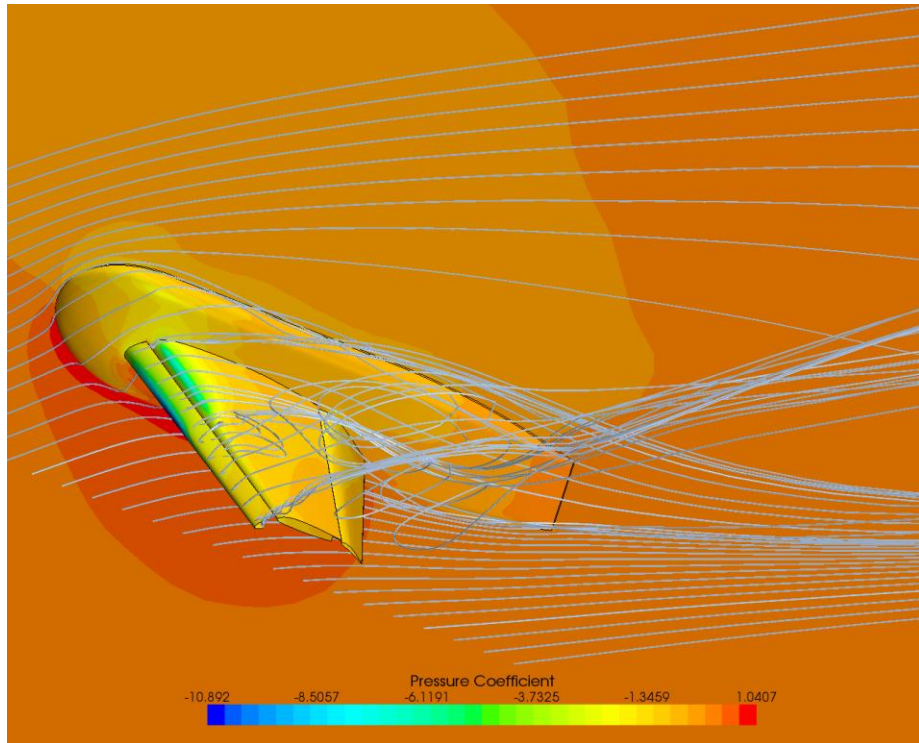
- Subsonic Aircraft Roughness Glove Experiment (SARGE).
- Passive laminar flow technology increases the laminar flow region on a swept wing and reduces aircraft drag.
- Uses spanwise-periodic, micron-sized discrete roughness elements (DRE's).
- Requires low freestream turbulence levels found in flight.
- Significantly increases the laminar flow region over a swept wing at lower Mach numbers and Reynolds numbers in flight.
- The Dryden GIII SCRAT aircraft helps extend the flight research of the DRE laminar flow technology to higher Mach numbers and Reynolds numbers representative of full-scale jetliners.

# GIII Aircraft Wing Modifications by the SARGE DRE Laminar-Flow Wing Glove



- Glove spans approx. 30% of the aircraft wing's halfspan.
- Smaller leading edge (LE) radius.
- Longer chord length.
- A smaller thickness over chord (t/c) ratio.
- Modified airfoil camber line.
- Two leading-edge snags introduced by the glove extending beyond the unmodified aircraft wing's leading edge.
- Four standard aircraft wing vortex generators (out of a total of 31) are removed on the left gloved wing.
- The clean right wing retains the full 31 vortex generators.

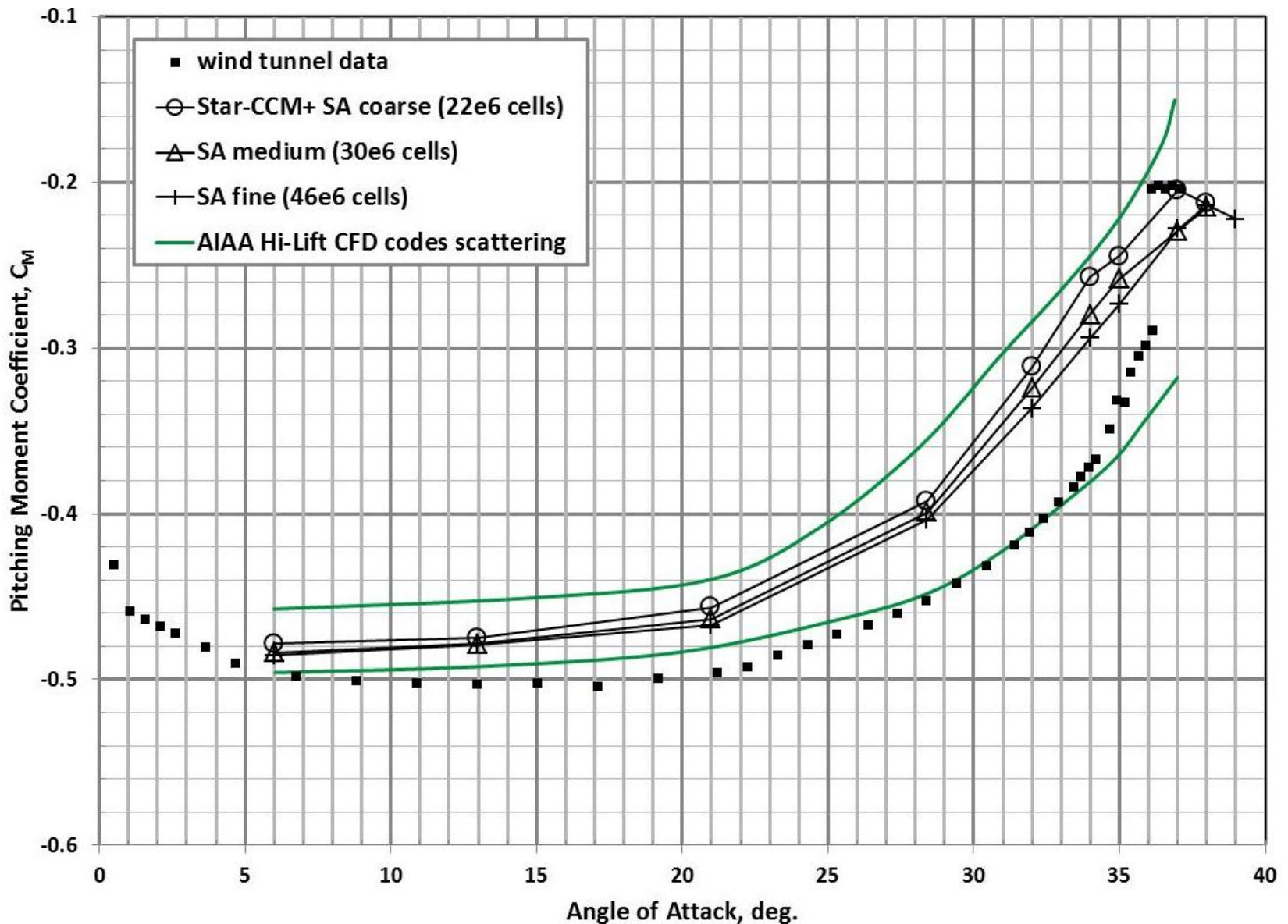
# Star-CCM+ Validation Study



- Star-CCM+ code was validated using the First AIAA CFD High-Lift Prediction Workshop wing-body geometry.
- Wing-body configuration 1 with 30-deg. slat and 25-deg. flap.
- Mach 0.2, Reynolds no. of 4.3 million based on MAC.
- Used recommended best practices from the workshop for Star-CCM+ stall validation runs.
- Need low  $y^+$  turbulence modeling option for best results.
- Accuracy of Star-CCM+ results is within the range of the CFD codes considered at the workshop.
- Star-CCM+ is able to predict wing stall to within 1 degree of AOA as compared to wind tunnel test data

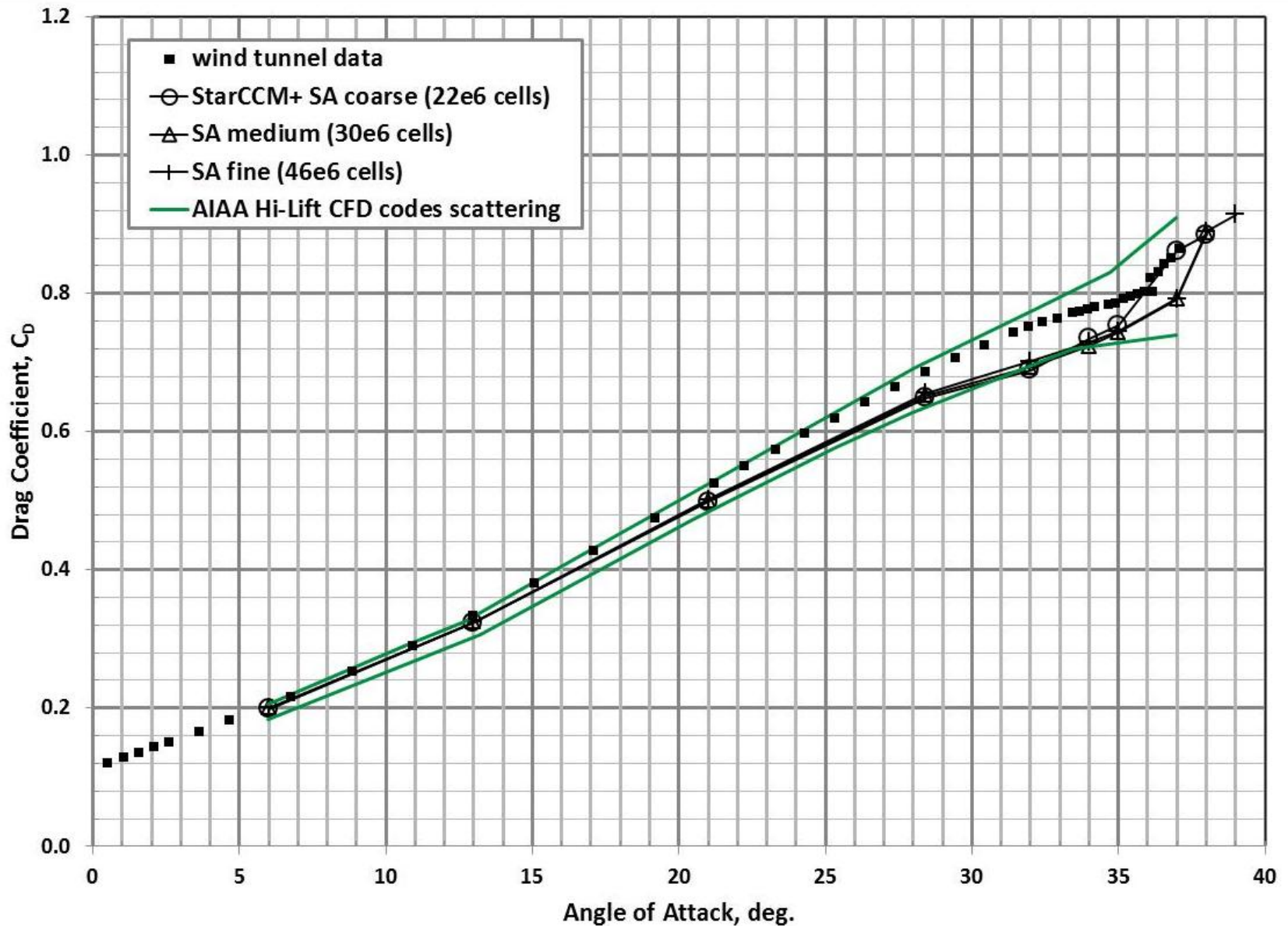


# CFD Code Validation Results

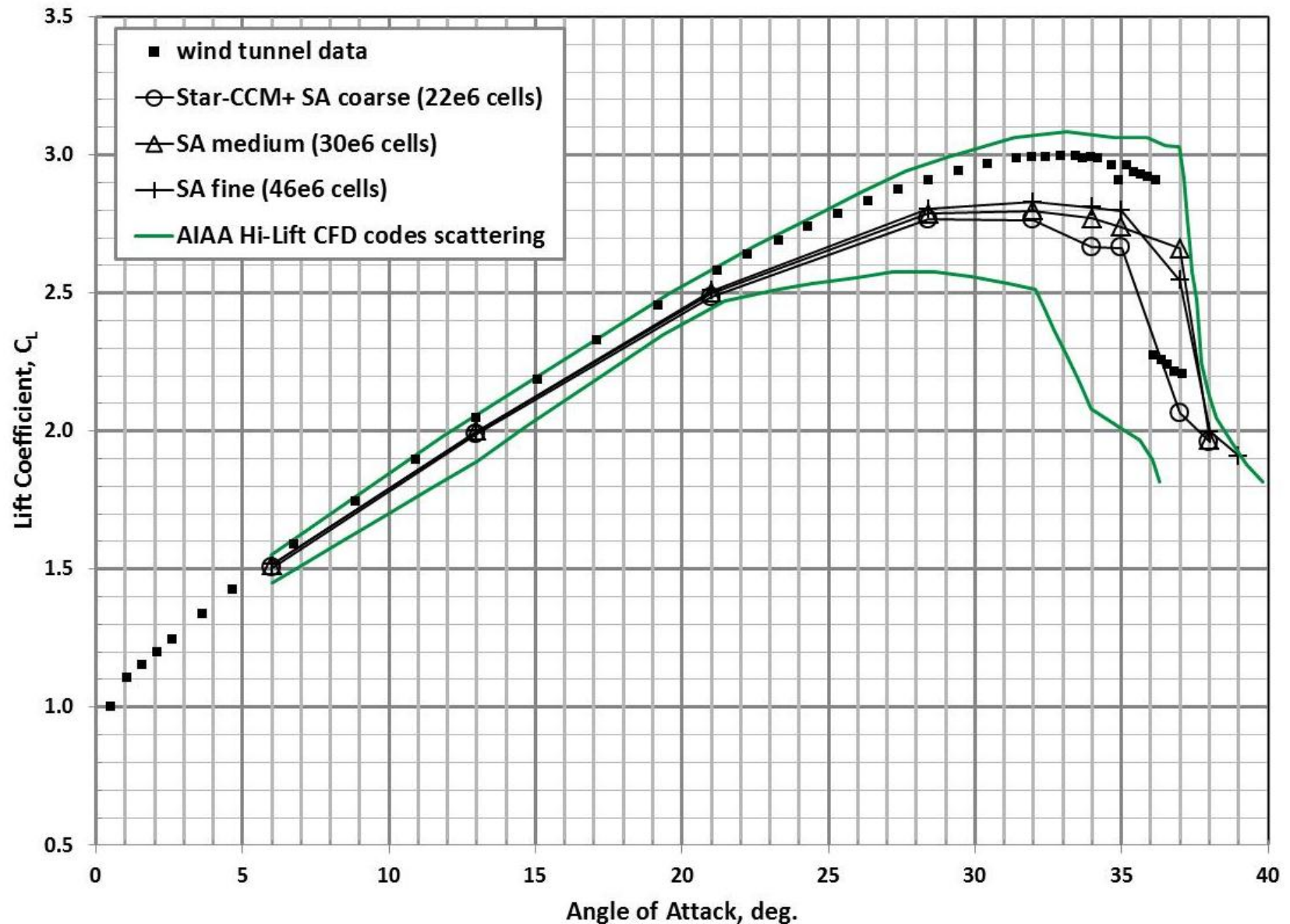




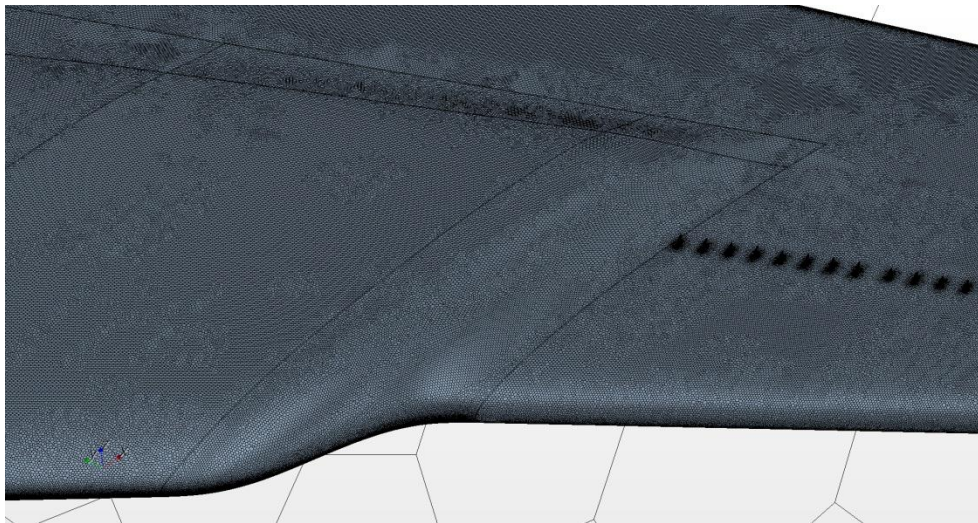
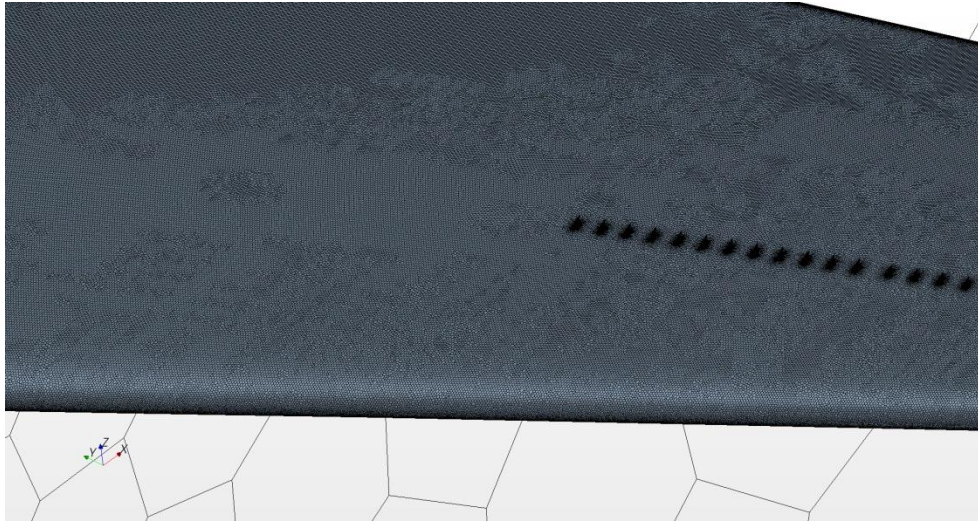
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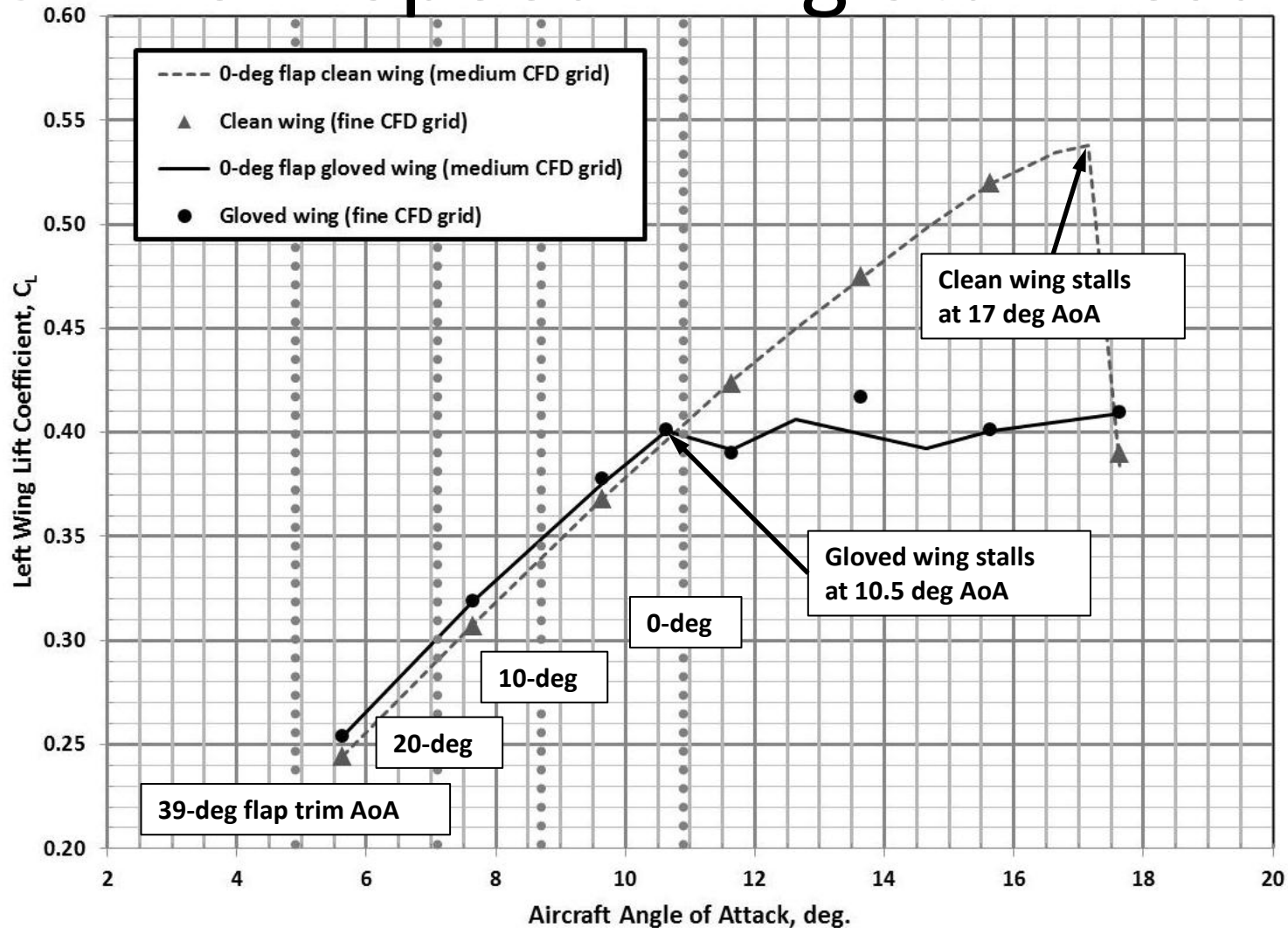
# Details of the GIII Wing CFD Simulations



- Two mesh densities were used: medium (35 million cells) and fine (45 million cells).
- Fully turbulent simulations.
- Low  $y^+$  turbulence modeling option was used with the first  $y^+$  value from the wall around 0.1.
- Approximately 19 prism layers were used in the boundary layer over the wing, with a overall prism layer thickness of 0.055 m.
- Far-field boundaries are placed approximately 100 times the MAC away from the wing.
- For the medium mesh, surface target mesh size is 0.3% of the MAC (minimum mesh size is 0.075% MAC).
- Surface mesh growth rate of 1.2.
- Volume cell growth rate of 1.2.
- Simulations were started at 6-deg AoA then gradually increasing the freestream AoA values until past lift stall.
- The converged solution is used to start the next higher AoA CFD simulation.
- Convergence is achieved when forces and moments, as well as all of the residuals become either constant or periodic.

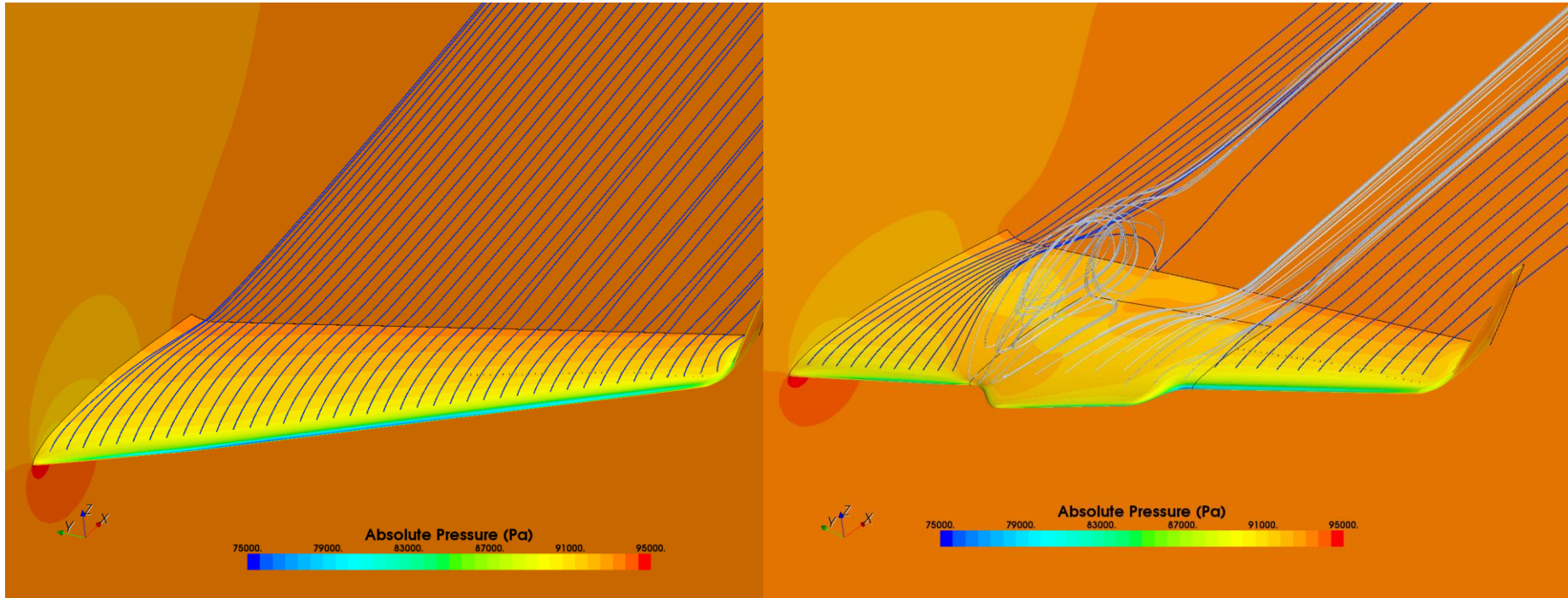


# GII Low-Speed Wing Stall Results



Mach 0.183 (120 knots), 2300 ft. ASL, left wing only with a symmetry plane, 0-deg. flap, with vortex generators.

# Gloved Wing Stall Visualization



Clean unmodified wing

Gloved wing

Mach 0.183 (120 knots), 2300 ft. ASL, 12-deg. AoA. Glove causes early wing stall as compared with clean unmodified wing.

# Conclusions and Recommendations

- Star-CCM+ CFD RANS code can produce hi-lift results that are within the spread of other CFD codes considered at the First AIAA High-Lift Prediction Workshop.
- Star-CCM+ CFD code was able to predict wing stall for the AIAA wing-body geometry to within 1 degree of angle of attack of the wind tunnel test data.
- Addition of the laminar-flow wing glove causes the modified and gloved aircraft wing to stall much earlier than the unmodified clean wing.
- The gloved wing also has a different stall characteristic than the clean wing, with no sharp lift drop-off at stall.
- These results have important flight safety consequences with potentially serious asymmetric aerodynamic forces and moments on the aircraft should the left gloved wing stalls.
- We need to investigate mitigations such as flap deflections and/or higher landing and take-off speeds.